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DOSIMETRY FOR LARGE ANIMAL EXPERIMENTS USING MULTIPLE Co^{60} SOURCES AND 1 MVP X RAYS

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ABSTRACT

A quadrilateral configuration of four movable uncollimated Co^{60} sources with a total activity of 9000 curies was used to obtain exposure measurements in air and depth doses in a masonite phantom for radiation experiments involving sheep. The depth dose distribution in the phantom in the four source exposure is compared to distributions obtained using a single collimated Co^{60} source four times in succession to simulate the four source array and exposure geometry, and to 1 Mvp X-rays in a bilateral exposure. Distributions of the quadrilateral gamma and X-ray exposures differed quantitatively by no more than 5% throughout the phantom thickness.

Ionization measurements were made in outdoor pens built to house one hundred sheep individually during chronic low-level exposures ranging from 500 mR/hr to 4 R/hr. Exposure rates at the two rows of pens were varied by using several source arrangements. Bilateral depth dose distributions in a sheep phantom exposed in the pens showed that the radiation from the uncollimated sources at the distances of the pens was less penetrating than from a collimated Co^{60} source at a closer distance (corrected for inverse square effect), and more penetrating than from 1 Mvp X-rays except at the phantom surfaces.

SUMMARY

This report discusses the geometric arrangements employed in acute and chronic radiation experiments involving sheep and presents results derived from measurements made at the exposure site and in a masonite sheep phantom.

INTRODUCTION

The outdoor Radiation (Exposure) Range of the U. S. Naval Radiological Laboratory provides a flexible arrangement for the use of four high-intensity uncollimated Co^{60} sources for radiation experiments (1,2). This report discusses dosimetry performed in conjunction with two phases of large animal experiments conducted at the range: Acute Exposure Studies and Chronic Exposure Studies. The experiments investigating acute mortality response and recovery of sheep from radiation injury, are described in another paper[a].

In the acute exposure studies, all four of the sources are used in a symmetrical arrangement to irradiate four sheep simultaneously. The depth dose distribution thereby obtained in a sheep phantom is compared to curves derived from exposures to bilateral 1 Mvp X-rays for use in similar X-ray experiments with sheep[a], and collimated Co^{60} gamma rays.

For the chronic exposure studies, extended isodose areas were mapped out for the simultaneous around-the-clock irradiation of many sheep at low exposure rates. Unilateral and bilateral phantom depth dose curves are presented for the chronic exposures as well as for 1 Mvp X-rays and collimated Co^{60} gamma rays.

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[a] Hanks, G. L., Page, N. P., Ainsworth, E. J., Leong, G. F., Alpen, E. L., Acute Mortality and Recovery Studies in the Domestic Sheep (Ovis Ovis) with Cobalt-60 and 1 Mvp X-rays, USNRDL-TR in preparation.

METHODS AND MATERIALS

The outdoor exposure site at the Radiation Range in Camp Parks, shown in Figure 1, has been described by Menkes and Tochilin (1) and the source calibrations reported (2). The range is equipped with four movable Co^{60} sources which are housed in 2-ton lead cylinders, 22 in. in diameter by 28 in. high, riding on flat cars on orthogonal intersecting railroad tracks. At the tracks' intersection, there is a 20-foot square concrete exposure pad with a center turntable, permitting the sources to be crossed over to opposite sides or at right angles. For exposures, the sources are raised out of their lead shields by remote control to a height of 3 feet above the plane of the central pad.

The four sources are approximately equal in activity with a maximum difference between them of about 4%. The average exposure rate was 2960 R/hr for a single source at 1 meter at the time these experiments were undertaken.

A 200-curie Co^{60} source, collimated by a 7° half angle conical bore in its lead shield, was used for calibration purpose and depth dose comparisons in these measurements.

X-ray exposures were made with the radial beam of a General Electric 1 Mvp X-ray Machine, Resotron 1000. Inherent filtration of the machine of 4 mm water and 5.4 mm Cu gave a half value layer of 2.0 mm Pb or an effective energy of 330 kev for the radial beam.

The following dosimeters were employed throughout this work: Silver phosphate glass squares[a], 8 mm x 8 mm x 4.7 mm, wrapped with lead foil of 12.5 mil thickness for energy independence down to about 50 kev; LiF thermoluminescent powder[b], 58 mg samples in polyethylene tubes; and ionization chamber dosimeters[c] with full scale meter readings of 200 mR, 2 R, 5 R, and 50 R. Paired dosimeters were used in all instances.

Depth dose measurements were obtained along the transverse midline of a cylindrical masonite phantom (12 in. diameter x 26 in. long)[d] used to represent the sheep. Holes were bored 1-1/2 in. apart in a removable plug at the midline, allowing for a total of nine ionization chambers to be placed along the diameter of the phantom, including those at the surfaces.

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a. Tokyo Shibura Electric Co., Ltd. (Toshiba), Tokyo, Japan. Glass read on the Toshiba Fluoro-Glass Dosimeter reader, FGD-3B.

b. Type TLD-100, Harshaw Chemical Co., Cleveland, Ohio. LiF read on the Con-Rad reader (Controls for Radiation, Inc., Cambridge, Mass.).

c. Landsverk Electrometer Co., Glendale, Calif. Ion Chambers read on the Landsverk L-64 Roentgen Meter.

d. Tochilin, E., <u>One Mev X-ray Machine</u>, USNRDL, Unpublished report, (1959).

Acute Exposure Studies

The experimental configuration for the simultaneous irradiation of four sheep with high exposure rates is illustrated in Figure 2, showing rectangular blocks at the animal positions. To determine the range of source distances to the center which would provide dose rates acceptable for the animal experiments, exposure rates were first calculated at a number of points along a diagonal of the pad in the plane of the sources, assuming the sources to be equidistant from the center.

Optimum positions for the sheep were then precisely determined with dosimeters for the various source distances. Vertical exposure distributions were measured as well as horizontal, since in previous measurements made at the range (2) it was found that the vertical exposure profile at any position above the pad is a complex function of the scattering from the housing of all of the sources together and the ground/air interface (3,4). Thus, dosimeters were positioned on wooden dowels placed 2 feet apart along a single diagonal from one corner of the pad to the diagonally opposite corner, and from 1 foot above the pad to 5 feet at vertical intervals of 1 foot. No adjustments were made for asymmetry due to differences between individual sources.

Separate measurements were undertaken to estimate the effect of source distance of the vertical scattering profile, all other geometric factors remaining the same. For these measurements, the four sources were arranged symmetrically about the pad at a selected distance and a single wooden dowel was placed on a diagonal at the center of one of the already determined exposure positions. Exposures were made with paired sources, the "near" sources being adjacent to the dowel on either side at a distance of 3.25 meters, and the "far" sources, at 7 meters.

Depth dose measurements were obtained in the masonite phantom inside a wooden box used for holding the sheep in a fixed position during exposure. The box, with inside dimensions 42 in. x 18 in. x 30 in. deep, was constructed of 1/4 in. plywood and reinforced along the edges with 2 in. x 4 in. wooden beams. It was centered at the exposure position, aligned lengthwise along the diagonal, and raised off the pad to the height at which vertical nonuniformity in the animal exposures would be at a minimum, as determined from the vertical distributions obtained previously.

The combined effect of absence of source collimation, simultaneous backscatter from all of the source shields, and attenuation or scatter due to the wooden enclosure was estimated by comparing depth doses from the quadrilateral exposure to depth doses in the same phantom (unboxed) exposed to the collimated Co^{60} source. The geometry of the four source array was simulated by cumulatively exposing the phantom to 1 Mvp X-rays administered bilaterally in two separate exposures and employing the wooden box described above. The distance from X-ray target to the box enclosed phantom (and sheep) midline in this case was 2.5 meters resulting in exposure rates more nearly comparable to those obtained in the acute exposures at the range where the closer pair of the four Co^{60} sources were at a distance of 3.25 meters from the midline.

Chronic Exposure Studies

Using representative combinations and arrangements of the track sources, isodose curves were mapped out on the slopes overlooking the source enclosure at the range. An exposure rate of 500 mR/hr extending over a distance of 250 feet in an arc was obtained with a single source placed at the end of a track arm (uppermost source in Fig. 1). The arc nearly paralleled a contour line of the slope at a radial distance of about 60 meters. The curve of the arc was initially determined from rate meter readings and then adjusted by exposing ionization chambers at 10 foot intervals along the arc. Fifty pens were built along the resultant isodose line (upper row in Fig. 1), each 5 ft. wide x 10 ft. deep.

A lower row of pens was built at a radial distance of 40 meters from the single source at the track end to provide twice the original exposure rate. Low exposure levels available thus ranged from 500 mR/hr in the upper row of pens using a single source, to approximately 4 R/hr in the lower row of pens, using four sources placed as close together as possible along the single track.

The masonite sheep phantom was irradiated in both rows of pens as well as with the collimated Co^{60} source at the laboratory at a distance of 8 meters and with a 1 Mvp X-ray beam at a TSD of 3.25 meters, distributions of the latter two being corrected for the inverse square effect. The X-ray exposure in this experiment differed from the acute X-ray exposure insofar as the phantom here was placed at a greater distance from the target and was in open air rather than in the wooden box. In all cases the cylindrical axis of the phantom was oriented normal to the direction of the incident beam of primary radiation.

Bilateral distributions were computed from the unilateral depth doses since it was assumed that the sheep in the pens would receive, on the average, the equivalent of a bilateral exposure during the course of the experiments.

RESULTS AND DISCUSSION

Acute Exposure Studies

Figure 3 shows the exposure rates calculated on a simple inverse square basis and the exposure rates measured in the plane of the sources along a diagonal of the central pad with the four sources symmetrically positioned at distances ranging from 3 to 7 meters from the center. More uniform distributions result along the horizontal as the sources are moved outwards, with positions of maximum exposure being shifted towards the corners of the pad. For the actual sheep irradiations, all four sources were located 4.5 meters from the center of the pad, and boxes for retaining the sheep were centered on a diagonal 9 feet from the center, the maximum exposure position for this source distance. This resulted in no more than a 5% variation in exposure along the 42 inch length of the box.

Variation of exposure in the vertical direction above the pad along the diagonal (from glass dosimeters) is shown in Figures 4a, b and c for source distances to the center of 3, 4 and 5 meters, respectively. Exposures averaged from readings of like dosimeters along the diagonal for each source distance, and normalized for each height "x" to the exposure at the same position at the 3-foot level, appear in Table 1 as ratios $\frac{E_{x\ \text{feet}}}{E_{3\ \text{feet}}}$.

TABLE I

Average Vertical Exposures Above Concrete Pad Normalized to 3-foot Level

Dosimeter	No. of Sources	Source Dist. from Center (meter)	$\frac{E_{5\ \text{feet}}}{E_{3\ \text{feet}}}$	$\frac{E_{4\ \text{feet}}}{E_{3\ \text{feet}}}$	$\frac{E_{2\ \text{feet}}}{E_{3\ \text{feet}}}$	$\frac{E_{1\ \text{foot}}}{E_{3\ \text{feet}}}$
Glass	4	3		1.07±.02	1.12±.04	1.09±.04
	4	4		1.08±.02	1.10±.02	1.14±.02
	2(near)	4.5	1.16	1.10	1.11	1.11
	2(far)	4.5	1.13	1.09	1.14	1.10
	4	5		1.08±.02	1.09±.03	1.11±.02
	4	5	1.11±.02	1.09±.02	1.07±.03	1.15±.03
LiF	4	3		1.15±.07	1.10±.11	1.21±.08

Table 1 (Cont'd)

Average Vertical Exposures Above Concrete Pad Normalized to 3-Foot Level

Dosimeter	No. of Sources	Source Dist. from Center (meter)	$\frac{E_5 \text{ feet}}{E_3 \text{ feet}}$	$\frac{E_4 \text{ feet}}{E_3 \text{ feet}}$	$\frac{E_2 \text{ feet}}{E_3 \text{ feet}}$	$\frac{E_1 \text{ foot}}{E_3 \text{ feet}}$
LiF	4	4		1.10±.05	1.11±.04	1.15±.04
	4	5		1.06±.03	1.08±.03	1.09±.04
Ionization	2(near)	4.5	1.09	1.10	1.09	1.14
Chambers	2(far)	4.5	1.19	1.11	1.04	1.15

The effect of source distance on the vertical scattering profile as measured by exposures of the paired sources and listed in Table 1, is shown in Figure 5. For the particular experimental environment discussed here, it appears that the scattering above the pad at any level decreases as the horizontal distance to the sources increases. However, the height above the pad at which the scattering is a minimum remains consistently at 3 feet with a reasonably symmetrical increase about that level upwards to 5 feet and downwards to 1 foot. With the sheep centered at the 3 foot level for the acute exposures, the maximum variation from top to bottom surface of animal was no more than 5%. The final expousre rate measured at the center of the animal box was 11 R/min.

Relative depth dose distributions in the phantom obtained with the four source array, a collimated Co^{60} source, and 1 Mvp X-rays are shwon in Figure 6. The upper set of curves are the distributions normalized to the front surface dose, and the lower set are the distributions relative to the air exposure at the midline of the animal exposure volume. A comparison of the gamma curves in the lower set shows that the phantom was subjected to a higher average exposure at the range than would have been the case if a single collimated source had been used four times in succession in the same geometry. However, except at the phantom surfaces where scattering from the heavy framework of the animal retainers apparently enhanced the dose, the rate of absorption in the phantom is almost the same for both (the curves are almost parallel). Uniformity in depth dose sacrificed on this account is revealed more clearly in the normalized curves in the upper part of Figure 6.

On the other hand, the relative depth dose distribution from 1 Mvp X-rays is of a distinctly different shape than the gamma distributions. Despite this difference, it was possible to match the curves of the bilateral X-ray and quadrilateral gamma depth dose distributions to within 5% of each other at every point by the choice of a suitable X-ray target distance and appropriate midline air exposure rates.

Chronic Exposure Studies

The exposure levels to which the sheep were subjected in the upper row of pens at 60 meters (500 mR/hr) varied only 8% in 10 feet of depth from front to rear of pen. Rate meters and dosimeters showed no consistent variation in exposure up to a height of 4 feet above the ground at that distance. Similarly, the variation in exposure in the lower row of pens was no more than 15% from front to rear of pen. Where four sources were used, two of them being displaced about 3 meters from the original point location at the end of the track, the exposures measured in the center of each pen over the extent of the arc deviated from the average by no more than 5%.

Figure 7 shows the relative depth dose distributions in the sheep phantom for the exposure conditions described earlier. The unilateral depth doses relative to the midline air exposures are almost identical at the entrance surfaces of the phantom for the three separate irradiations with Co^{60}, since there were in all cases a minimum of scattering interfaces in the immediate proximity of the phantom. A more perceptible difference between the curves at the surfaces is evident in the bilateral exposure. In both cases, the distributions obtained at 40 and 60 meters are indistinguishable from each other but the depth dose ratios are a few percent lower than in the 8 meter exposure.

The unilateral X-ray curve obtained at 3.25 meters shows the approximate magnitude of the contribution from backscatter, resulting in a surface dose 18% higher than that of Co^{60} and exit dose about 10% lower. However, a bilateral exposure at an appropriate X-ray target distance partially balances this disparity, bringing the X-ray from front to rear of pen. Rate meters and dosimeters showed no consistent variation in exposure up to a height of 4 feet above the ground at that distance. Similarly, the variation in exposure in the lower row of pens was no more than 15% from front to rear of pen. Where four sources were used, two of them being displaced about 3 meters from the original point location at the end of the track, the exposures measured in the center of each pen over the extent of the arc deviated from the average by no more than 5%.

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CONCLUSIONS

The contribution of scattering to the radiation field of a number of uncollimated gamma sources is evidently a complex function of all the interfaces within reasonable distances of the measuring devices. It cannot be assumed categorically that the dose at any point in such a field can be predicted on the basis of measurements made with identical collimated sources in a similar geometry.

In particular, in this experimental environment, it was found that at any position in the proximity of the uncollimated sources, the scattering contribution increased in both vertical directions from the source level, upwards as well as downwards towards the ground interface.

Depth dose curves along the transverse midline of a cylindrical phantom used to represent a sheep reveal that under certain conditions, 1 Mvp X-rays (330 kev effective energy) closely resemble uncollimated Co^{60} gamma rays in large animal experiments.

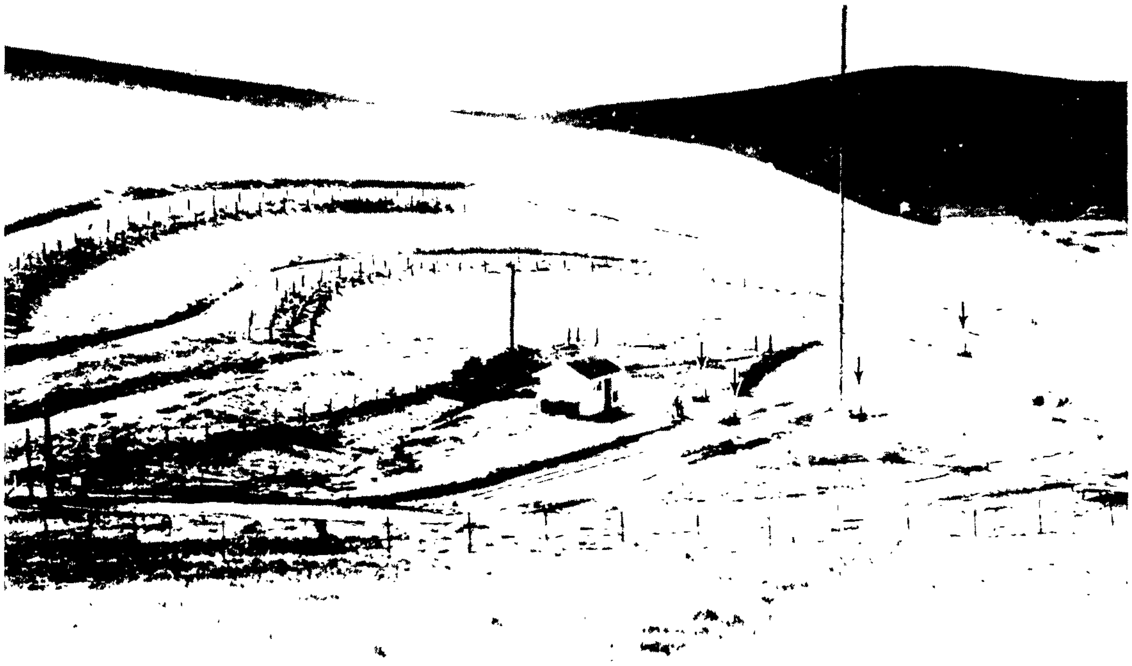

Fig. 1 USNRDL Radiation (Exposure) Range. Arrows indicate sources.

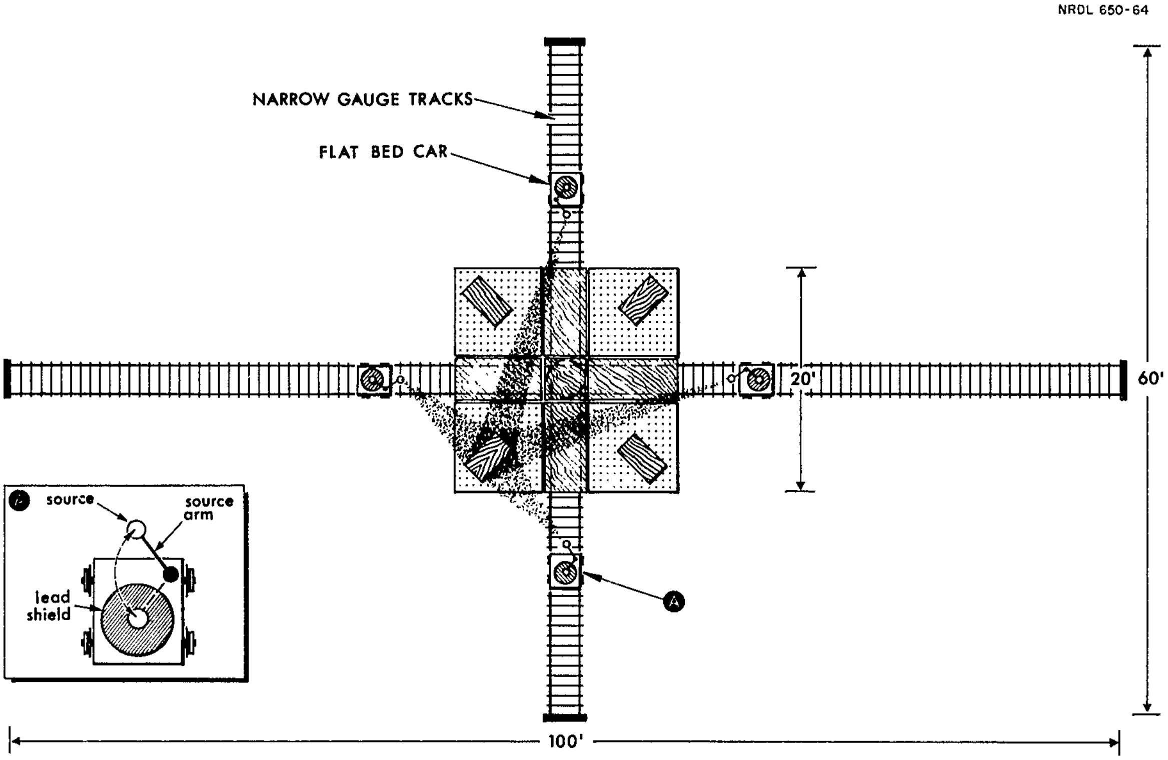

Fig. 2 Acute Exposures - Experimental Arrangement.

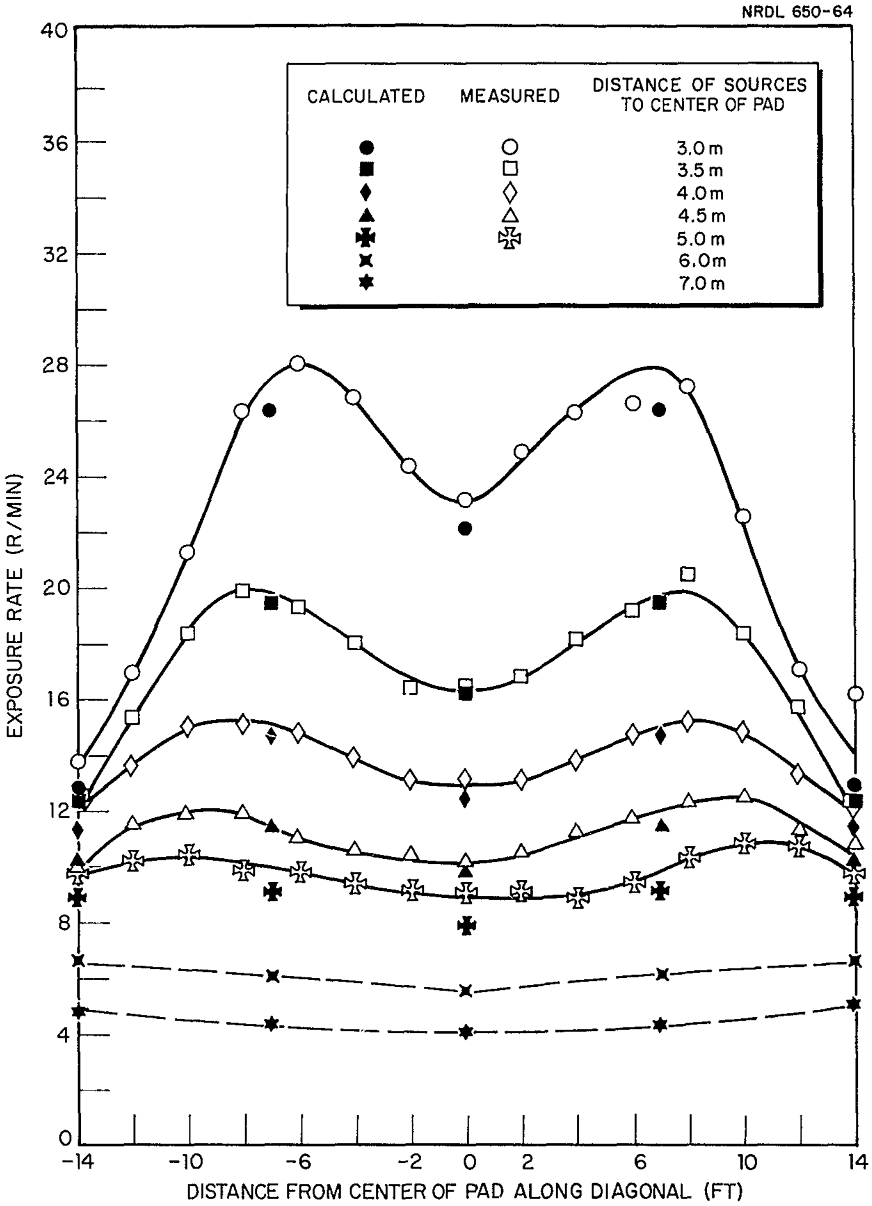

Fig. 3 Exposure Distribution along Diagonal in Plane of 4 Sources for Various Source Distances to Center of Pad.

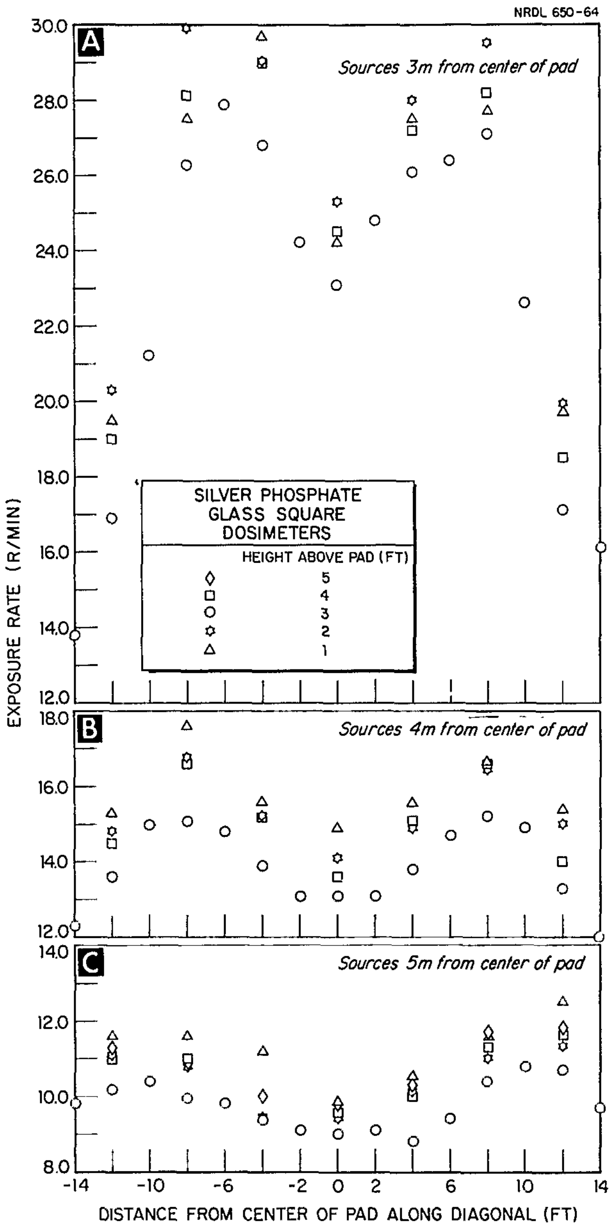

Fig. 4 (a, b and c) Vertical Exposure Distributions Along Diagonal for Quadrilateral Source Arrangement.

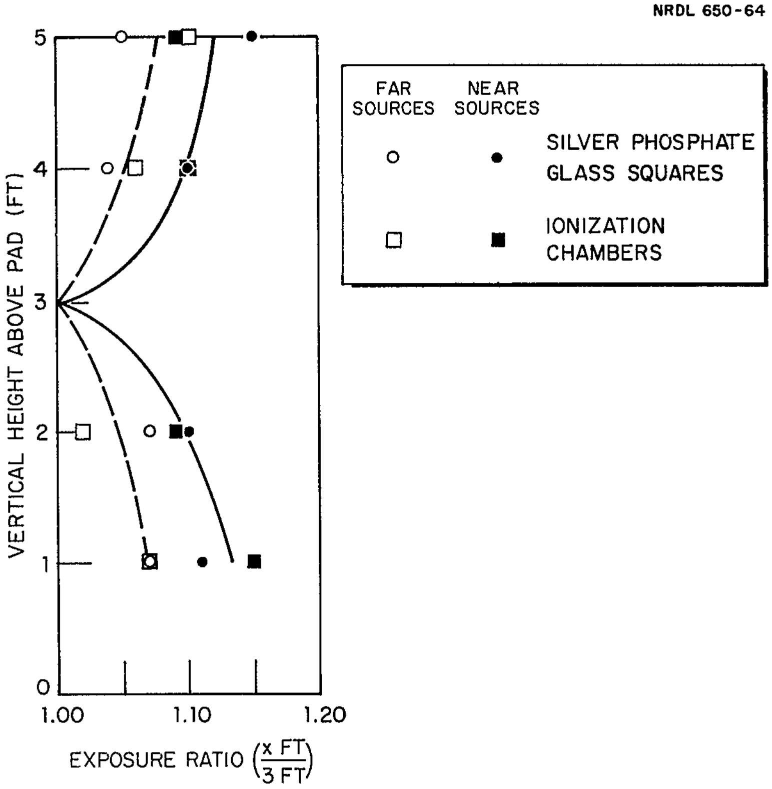

Fig. 5 Vertical Exposure Profiles at One Position on Diagonal Using Paired Sources.

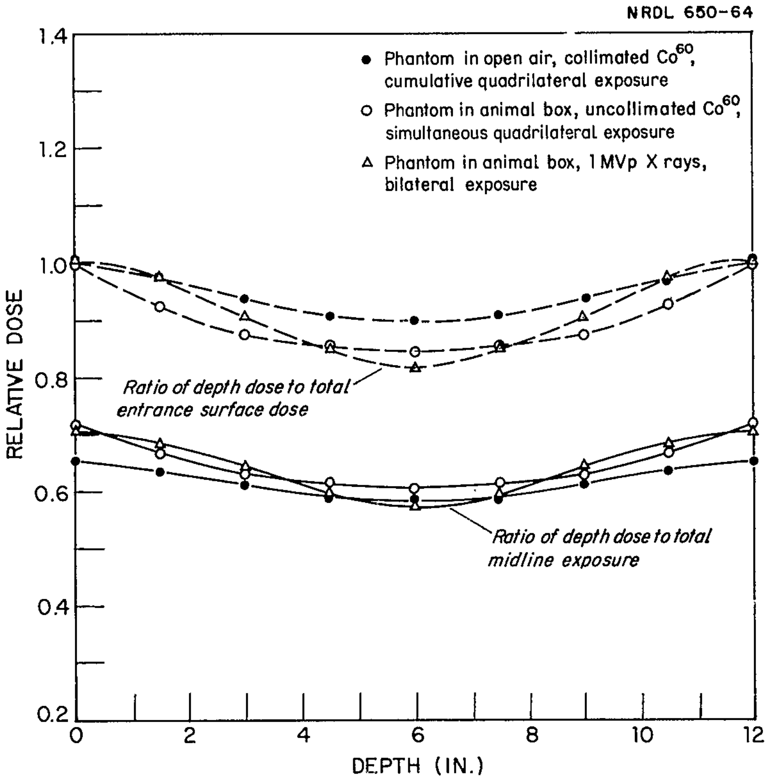

Fig. 6 Acute Exposures - Relative Depth Dose Distributions Along Transverse Midline of Phantom.

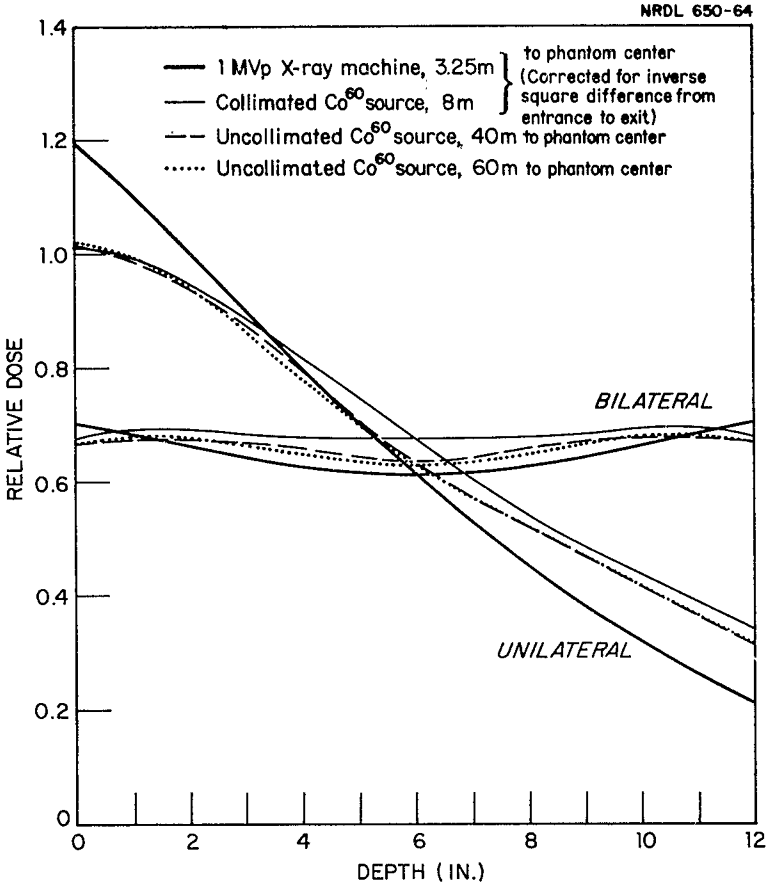

Fig. 7 Chronic Exposures- Depth Dose Relative to Midline Exposure Along Transverse Midline of Phantom.

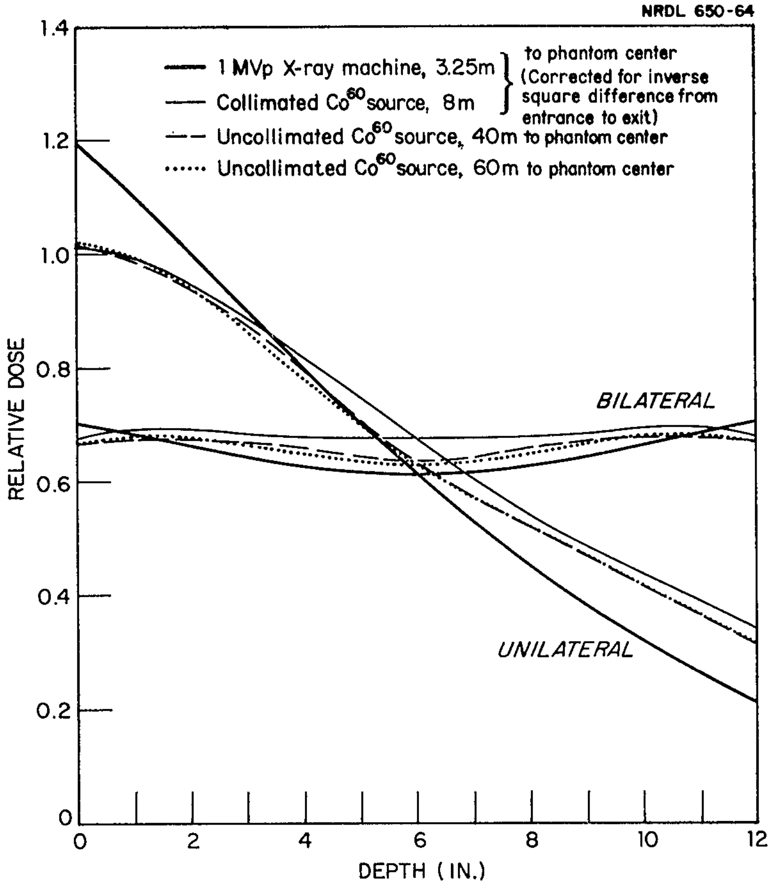

Fig. 7 Chronic Exposures- Depth Dose Relative to Midline Exposure Along Transverse Midline of Phantom.

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It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

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